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Fire and Western Spruce Budworm History in the Jemez Mountains

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Abstract

We evaluated potential relationships between fire and western spruce budworm outbreak histories in the Jemez Mountains of northern New Mexico. Our goal was to investigate possible interactions of these two primary disturbance agents in mixed-conifer forests. The timing and trends in budworm outbreak patterns were compared to individual fire events as well as to fire frequency trends and relative fire extent. Graphical comparisons of fire and budworm histories in five mixed conifer stands failed to identify any consistent pattern of association between these disturbance events. No associations were visually evident at either decadal-scales or annual scales. Given the lack of clear and convincing patterns in the graphical assessments, statistical tests of association were deemed inappropriate at this time. The budworm histories were relatively short, with good sample depths only after about 1800 in most sites, whereas the fire histories typically had good sample depths back to 1700 or earlier. If future tree-ring studies in the Jemez Mountains could lengthen the budworm histories it would be possible to more fully evaluate fire-budworm associations over longer periods of time. This may increase the opportunity to identify annual to decadal-scale associations because more budworm outbreaks would be confidently reconstructed, thus increasing the length of the temporal comparisons with fire trends and events.

Introduction

Disturbance ecologists, entomologists and foresters have long suspected that insect outbreaks and forest fires were correlated in space and time (Schowalter et al.

1986, Hadley et al. 1993, Fleming and Candau 1998, Radeloff et al. 2000). The die-off of conifer forest canopies during insect outbreaks generates large quantities of dead fuels that can quickly increase the hazard of fire ignition, spread, and severity. Attack by stem feeders (e.g., bark beetles) often results in tree death with large quantities of drying foliage persisting on the stems for a year or more. During the outbreaks, and in the years immediately following, the dead needles persisting in conifer tree canopies can be extremely flammable, and these aerially-suspended fuels can promote the initiation and propagation of intense crown fires. Fire hazard may change in complex ways in subsequent years as dead foliage, small branches, and large stems accumulate on the forest floor. The trends and changes in fire hazard as a function of time since insect outbreaks are largely unknown. Although probable synergisms between insect outbreaks and forest fires have long been speculated upon, only a few studies have quantitatively evaluated these relationships (e.g., Stocks 1987, Fleming et al. in review).

Outbreaks of some defoliators such as the western spruce budworm may not always kill trees outright, but the quantity of dead foliage within stands increases during outbreaks. This occurs because feeding by the budworm larvae is usually incomplete, with partial consumption of some needles, damage to growing meristems in the branch tips, and die-off of entire branches. A result of these feeding behaviors and damage to tree crowns is that during and after the active feeding periods the affected trees retain a substantial amount of dead needles and fine branches. Moreover, the stresses that defoliation imposes upon host trees predisposes them to attack by secondary insects (especially bark beetles) leading to mortality. A consequence of budworm outbreaks may therefore be an increased likelihood of fire occurrence and spread, and/or an

increased likelihood of crown fires.

Synergism between insect outbreaks and fires may also work in the opposite direction. Fire occurrence could either predispose or forestall insect outbreaks, and both short and/or long-term associations might exist. For example, in the short-term (i.e., years or less) surface fires in forest stands could be harmful to insect populations through negative impacts of smoke or heating on the insects. Alternatively, surface fires or mixed severity fires (i.e., combinations of surface and fine-scale crown fires) might damage trees and thereby increase tree stress levels, which could promote some kinds of insect attacks. Large crown fires obviously destroy forests, and so the food base required to support large outbreaks can be removed for long periods (i.e., decades to centuries). Although these potential synergisms have been noted, very little quantitative research has been conducted evaluating such associations, particularly over significant time periods (i.e., decades and centuries).

Our aim in this study was to evaluate possible associations between fire and budworm outbreaks, utilizing long-term histories from both disturbance types. We made use of the fortuitous existence of tree-ring evidence of these disturbances in the same mixed conifer stands in northern New Mexico. Fire histories were reconstructed using fire-scarred trees and budworm outbreak histories were reconstructed using tree-ring growth responses of host trees (Douglas-fir and white fir) that were defoliated (but survived) during past outbreaks. Ring growth in a non-host tree species (ponderosa pine) was used to distinguish budworm outbreaks from drought effects (Swetnam et al. 1985, Swetnam and Lynch 1993). In this report, we address these primary questions: Was there a consistent pattern in the relative timing of fires and budworm outbreaks over the

past three hundred years? For example, did fire events usually precede outbreaks or vice versa? Were there consistent lags in the timing? Did fewer or more fires occur during outbreaks, or between outbreaks?

Study Area

A total of five mixed-conifer sites, from which either a budworm or fire history chronology had previously been developed (Swetnam and Lynch 1993, Touchan et al. 1996, Morino et al. 1998), were re-sampled and analyzed so that each site had both budworm outbreak and fire histories (Figure 1, Table 1). The sites named East Fork, West Vallecitos, Los Griegos, and Frijoles Canyon had existing budworm chronology reconstructions (Swetnam and Lynch 1993). A new budworm outbreak history was assembled at the Canada Bonito site using increment core collections from Douglas-fir and white fir trees obtained as part of an age structure and fire history study at this site (Touchan et al 1996, Morino et al. 1998). Existing fire-scar collections and fire chronologies were already available at the Frijoles, Los Griegos, and Canada Bonito sites. New fire-scar collections were obtained and fire chronologies developed at West Vallecitos and East Fork sites.

All sites were characterized as "mixed conifer", meaning that a combination of Douglas-fir (*Pseudotsuga menziesii*) , white fir (*Abies concolor*), and ponderosa pine (*Pinus ponderosa*) were present in varying amounts in all stands. Other tree species present in some stands included aspen (*Populous tremuloides*), limber pine (*Pinus flexilis*), and Rocky Mountain maple (*Acer glabrum*).

Other budworm and fire history sites were previously sampled in the Jemez Mountains (Figure 1) (see Swetnam and Lynch 1993 for a complete description of these sites and methods of budworm outbreak reconstruction). The other budworm sites included stands named Fenton Lake, Barley Ridge, and Peralta Canyon. In addition to comparison of fire and budworm histories within sites, a larger landscape-scale assessment was carried out by combining the five sites with the other budworm histories in the Jemez. Likewise, fire history chronologies in several additional sites in the Jemez were combined with the five fire-scar chronologies from the budworm/fire sites. These additional fire-scar chronologies were those sites nearest to the budworm/fire sites, and included chronologies from Bandelier National Monument, Monument Canyon Research Natural Area, and the Camp May area (near to the Canada Bonito site west of Los Alamos). The idea behind these landscape scale analyses were to assess the possible associations of very broad scale budworm and fire events and trends in the general area of the study sites of the Jemez Mountains.

Methods

Dendroecological methods were used to date, measure, standardize, and analyze all materials and data, as described in various publications (Swetnam et al. 1985, Baisan and Swetnam 1990, 1997, Swetnam and Lynch 1993, Swetnam et al. 1995, Swetnam and Baisan 1996, Swetnam, Kaib and Baisan 2001, Swetnam and Baisan 2002). Summaries of these methods are included below.

Budworm Reconstructions

Originally, western spruce budworm histories were reconstructed using averaged tree-ring width chronologies from sets of Douglas-fir and white fir trees . These "host" tree chronologies were "corrected" for climatic effects using "non-host" ponderosa pine chronologies from nearby areas (Swetnam and Lynch (1993). In the current study, we went back to the original ring-width measurements, and standardized these with 100-year length, 50% frequency response cubic splines using the program ARSTAN (Cook 1981, Cook and Holmes 1986). We then used the program OUTBREAK (Swetnam et al. 1995, Holmes and Swetnam 1996) to evaluate individual tree chronologies for all host trees within each of the sites. The program OUTBREAK utilizes a non-host chronology (in this case the average of the ponderosa pine tree-ring index chronologies from four sites in the Jemez Mountains) to correct (remove) year-to-year climate variations that are common to both host and non-host series.

Next, OUTBREAK evaluates the corrected series for characteristic patterns that are typical of the effects of defoliation by budworm. These characteristics are sustained growth reductions for a number of years (i.e., ring-width index values below the smallest decile of all ring index values in the chronology for more than four years). The program OUTBREAK identifies probable events within individual tree series, and then sums up the number of trees recording outbreaks during each year of the combined record from all trees within the stand. (See the cited references above for more details on these methods, and verification of outbreak timing using independent documentary records.)

The output of OUTBREAK includes (among other things), a summary time series

of numbers of trees showing evidence of outbreaks each year for the set of trees input for each stand. These stand summary chronologies were used to compare with fire-scar chronologies from each of the same five stands. Additionally, all of the stand summaries were added together to produce a Jemez Mountains summary chronology of outbreaks, and this series was compared with the composite record of fire-scar chronologies from the Jemez Mountains.

Fire Reconstructions

Fire histories were reconstructed by sampling 10 to 30 or more fire-scarred trees within the five mixed conifer stands. Partial or full cross sections were taken through the basal scars using a chainsaw. Both live and dead trees were sampled. The sampled trees were well-preserved, multiple fire-scarred trees that were widely distributed throughout the sites where the budworm history increment specimens were obtained. Total sampled areas ranged from about 10 to 50 hectares.

All of the tree rings and fire scars were dated on finely sanded surfaces of the cross sections using standard dendrochronology and fire scar dating techniques (Dieterich and Swetnam 1984). Fire dates were entered in the FHX2 database format and analyzed with this software (Grissino-Mayer 2001). Master fire chronology charts were prepared, which illustrate the spatial and temporal synchrony and trends in fire scar events across the site.

To evaluate the patterns of decadal-scale changes in fire frequency we computed running-period fire frequencies (number of events per period), and running period mean

percentages of trees scarred (Fig. 5). These series show the summed number of fire events and averaged percentage of trees scarred, respectively, within windows of time. The windows are computed sequentially for each period in the time series, moving forward one year for each period, and plotted on the central year.

Budworm and Fire Chronology Comparisons

We compared the budworm and fire chronologies in several different ways. First, we graphically compared the time series by plotting the timing of budworm and fire events in each of the five sites on the same time series plots. Both decadal and annual-scale fire frequency patterns were compared with the budworm time series. We also produced and compared composite budworm and fire history time series from the five sites, and other budworm and nearby fire history sites in the Jemez. These graphical comparisons were used to assess possible consistent (or inconsistent) patterns of budworm outbreaks or fires during, preceding or following each other.

Results

Budworm and Fire Chronologies

The budworm histories from the five sites clearly showed the major outbreaks of the 19th and 20th centuries (Fig. 2). These outbreaks extended approximately from the 1780s to 1800s, 1820s to 1840s, 1860s to 1870s, 1880s to 1890s, 1910s-1920s, 1930s to

1950s, and 1970s to 1980s. Earlier outbreaks are evident in the 1700s, but we have lower confidence in the timing and magnitude of these events because sample sizes were low (usually < 5 trees). Sample sizes were also relatively low (< 10 trees) before 1850 in a couple of stands (Los Griegos and Frijoles Canyon). The timing varied somewhat between stands, but the major outbreaks generally coincide over the entire area (Fig. 3).

The fire scar chronologies are typical of ponderosa pine and mixed conifer sites in the Southwest, with fires occurring relatively frequently within stands until approximately 1880 to 1900, when cessation of frequent fires occurred (Fig. 4). This cessation is most likely due to the beginning of intensive livestock grazing in these areas, followed by increasingly effective fire suppression by government agencies after about 1910 (Swetnam and Baisan 1996, Touchan et al. 1998, Allen et al. 1996). The mixed conifer site at Canada Bonito is somewhat different from the other four fire-scar chronologies in this set. This relatively high elevation site shows somewhat longer intervals between fires than the other sites.

The moving period fire-scar time series (Fig. 5) shows that period length considered in the moving window can importantly affect the trends in the series. Different combinations of 10-year, 25-year, and 50-year moving periods were computed for both fire frequency and mean percentage trees scarred and then compared with the budworm series.

Comparisons

We found that none of these moving period combinations showed consistent

patterns of association (graphically) with the budworm series. For illustration purposes, we show here the moving period mean percentage scarred series that seemed to show some association (but not consistent in any case) with budworm series (Fig. 6). In addition to the moving period time series, we also compared sets of fire events that had greater than 10%, 20% and 50% of trees scarred with the budworm outbreak series (not shown). These fire events were, in general, the relatively widespread fires within the sites. The purpose of these comparisons were to determine if any association could be discerned between the timing of widespread fire events and budworm outbreaks. These comparisons failed to reveal any clear graphical patterns of association.

Likewise, comparisons of the Jemez Mountains composite time series of budworm outbreaks and fire events failed to show consistent patterns of association (Fig. 7). There did appear to be a co-occurrence of the declining phase of some outbreaks and extensive fire events at the scale of these composite series. For example, note that a relatively extensive (synchronous) fire event occurred near the end of the outbreaks in a number of cases (Fig. 7, Fig. 8). However, there were also some extensive fire events that occurred near the beginning and during some of the outbreaks. Again, no consistent, or clear pattern was evident.

There was a notable period of decreased budworm activity and fire frequency during the 1780s (Fig. 7). Another fire frequency low point during the 1840s, however, coincides with the opposite budworm pattern, i.e., an outbreak.

Discussion

We were somewhat surprised that we could not (yet) identify a clear pattern of association between the reconstructed budworm and fire time series from the Jemez Mountains. Both disturbances clearly have important impacts on the dynamics of mixed conifer forest stands, including effects on nutrient cycling, tree growth and productivity (affecting forest floor fuels), tree recruitment patterns and other processes. So, why do we not see any clear association? It could be that any associations are relatively weak, and/or that the reconstructions are too noisy and incomplete to allow us to detect these weak associations. For example, the fire scar chronologies are not very useful (in present form) for assessing fire severity. It could be that fire severity (i.e., impacts of fires on living plants), rather than frequency or relative extent, is the key fire regime variable that is associated with budworm outbreaks.

It is also the case that the budworm histories are relatively short, and it may require time series with many outbreaks in comparison with fire scar chronologies to detect patterns of association. In the current set of chronologies, we were only able to confidently compare the 19th centuries in the two records. The 20th century was lacking a fire-scar record of frequent, widespread fires because of fire suppression. The 18th and 17th centuries (although shown in Figs. 7 and 8) had low sample depths in the budworm chronologies, so the timing and magnitude of these events may not be very well represented.

The 20th century budworm history appeared somewhat different from the 19th century, and obviously the fire histories in these two centuries was drastically different. The budworm chronologies tended to show more synchronous events in the 20th century, as characterized by somewhat narrower peaks and deeper valleys during the 20th century

relative to the 19th century (Fig 3). This pattern was also observed in forest stands in the Colorado Front Range, and was hypothesized by Swetnam and Lynch (1989) to potentially reflect the effects of fire suppression and human land uses on budworm regimes. It was hypothesized that fire suppression and timber harvesting practices in the late 19th and early 20th centuries led to late 20th century stands that were more homogenous and dominated by budworm host trees species (Douglas-fir and white fir) than 19th century stands. These late 20th century stands may have been more prone to widespread and intense outbreaks than 19th century (and earlier) stands. Although this hypothesis has not been proven, and other tree-ring studies in the western US have only partly supported it (e.g., Swetnam et al. 1995, Ryerson et al. in review), the patterns suggesting this hypothesis remain the strongest indication that changes in fire regimes may be related to changes in budworm outbreak regimes.

Conclusions

We did not identify any clear association between surface fire regimes and budworm outbreak regimes in the Jemez Mountains. However, these results are not conclusive that no association exist, in part because the budworm record is not long enough for an adequate comparison. Extension of budworm outbreak histories would enable us to compare budworm and fire histories over a longer common period, which would increase the chances of identifying synchrony in events or similarity in trends. There are a number of stands in northern New Mexico, and southern Colorado, for example, where very long budworm chronologies exist (i.e., > 300 years) and fire

histories could be reconstructed. Additional fire history work aimed at determining which events within and among stands were more intense and severe might also be helpful in identifying fire regime variables that could be more strongly associated with budworm outbreak than fire frequency or extent.

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Table 1. Characteristics of fire and budworm sites in the Jemez Mountains

Site/Stand name	B/F/C[1]	Aspect (degrees)	Slope (%)	Elev. (m)	Stocking (m^2/ha)	Density (stems/ha)
Peralta High	B	10	30-60	2790	55.5	649
Peralta West	B	325-030	20-50	2720	65	629
West Vallecitos	B/F	30	40-60	2510	26.5	612
Los Griegos	B/F	345	50-60	2900	44.1	690
Fenton Lake	B	340-360	40-50	2500	41.1	834
East Fork	B/F	340-010	40-50	2495	51.0	740
Frijoles Canyon	B/F	230	10-20	2730	73.3	1052
Barley Ridge	B	flat	flat	2610	15.5	216
Bandelier 1	F					
Bandelier 2	F					
Bandelier 3	F	No data				
Bandelier 4	F					
Bandelier 5	F					
Capulin Canyon	F					
Monument Canyon	F					
Baca	C	150-180	50-60	2450		
Fenton lake	C	140-160	20-50	2750		
Abouselman Spring	C	180	60-80	2600		
Cat Mesa	C	130	5-50	2530		

[1]Sites with either budworm (B), or fire (F) chronologies, or both (B&F); and sites where tree-ring width chronologies from non-host ponderosa pine chronologies were developed (C).

Table 2. Number of tree-ring samples in fire and budworm sites.

Site/Stand name	B/F/C[1]	Number of Trees Sampled		
		Douglas-fir	White fir	Pinus
Peralta West	B	17	11	...
Peralta High	B	15	16	...
West Vallecitos	B/F	18(B)	18(B)	30(F)
Los Griegos	B/F	31(B)	20(B)	15(F)
Fenton Lake	B	17	12	...
East Fork	B/F	30(B)	32(B)	12(F)
Barley Ridge	B	15	14	...
Frijoles Canyon	B/F	14(B)	19(B)	10(F)
Canada Bonito	B/F	28(B)		
Bandelier 1	F	...	...	9
Bandelier 2	F	...	...	13
Bandelier 3	F	...	...	17
Bandelier 4	F	...	...	22
Bandelier 5	F	...	...	11
Baca	C	...	...	19
Fenton lake	C	...	...	12
Abouselman Spring	C	...	...	17
Cat Mesa	C	...	...	13

[1]Sites with either budworm (B), or fire (F) chronologies, or both (B/F); and sites where tree-ring width chronologies from non-host ponderosa pine chronologies were developed (C).

Figure 1. Study area in Jemez Mountains, New Mexico. Sites labeled "Other Fire History" or "Other Budworm History" are sites sampled and reconstructions developed in other studies cited in the text.

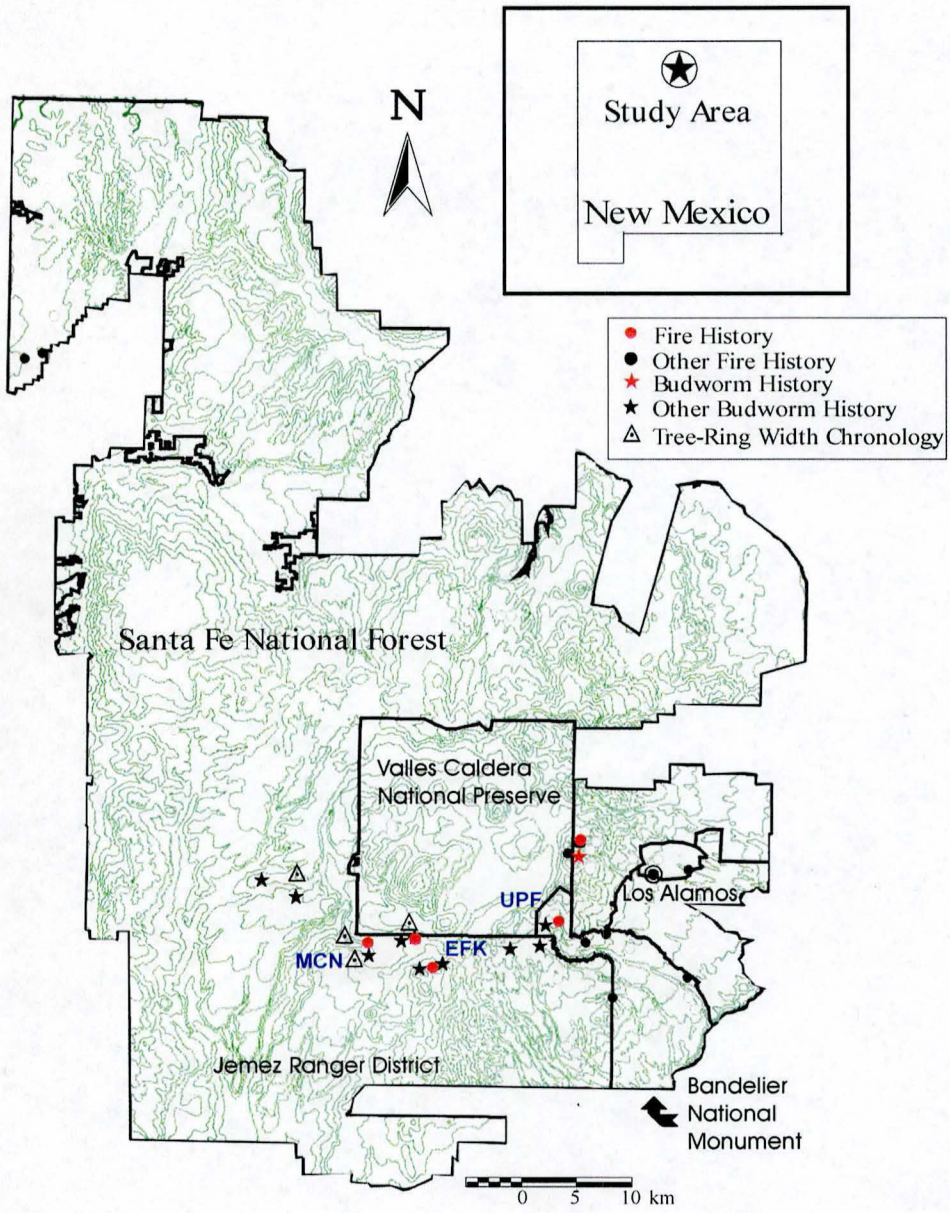


Figure 2. Number of trees recording outbreaks in the five study sites (solid line) and sample depth (dashed line, number of sample trees included in the data set).

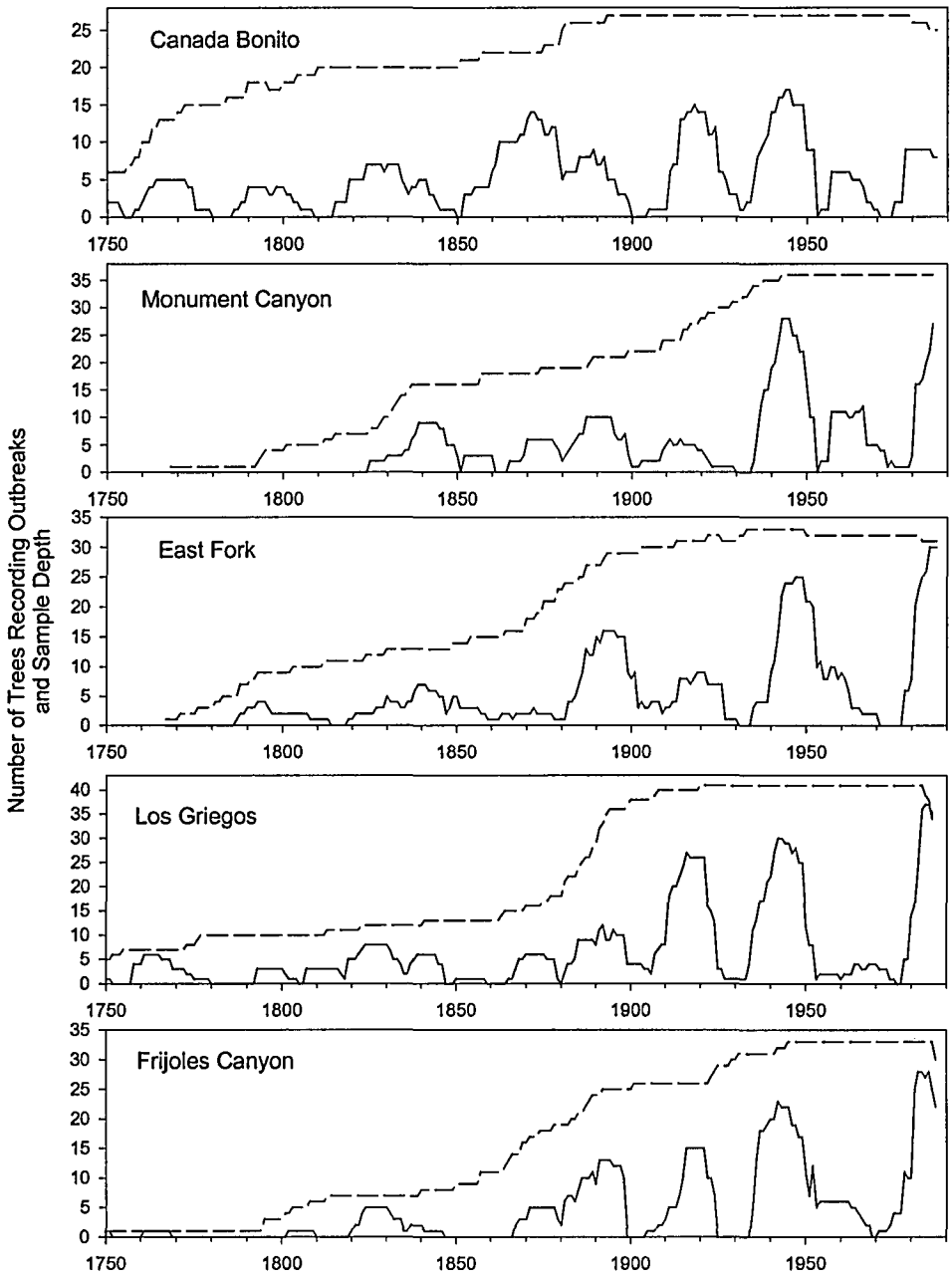


Figure 3. Composite budworm history in the Jemez Mountains. The budworm outbreak series (with peaks and valleys, corresponding to left y-axis) is the percentage of trees recording outbreaks in all sites relative to the total trees (sample depth) in all sites (smooth line corresponding to the right y-axis).

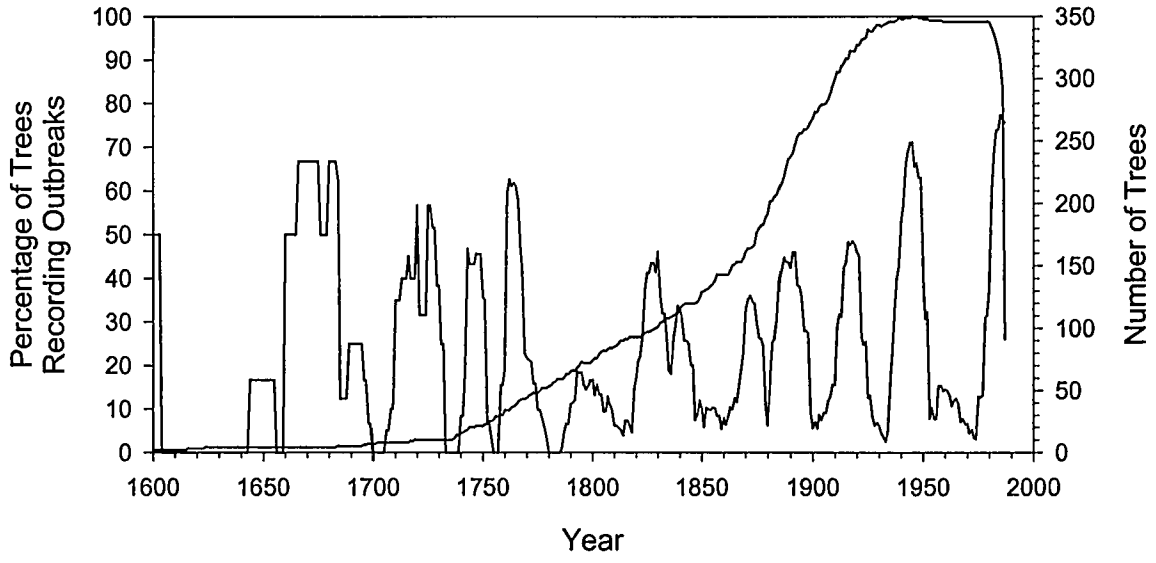


Figure 4. Master fire scar chronologies from two of the five sites. The upper chronology is from West Vallecitos (northeast slope near Monument Canyon) and the bottom chronology is from Canada Bonito. Note the fire event synchrony within sites, the change in fire occurrence after circa 1890, and the lower fire frequency in the Canada Bonita site.

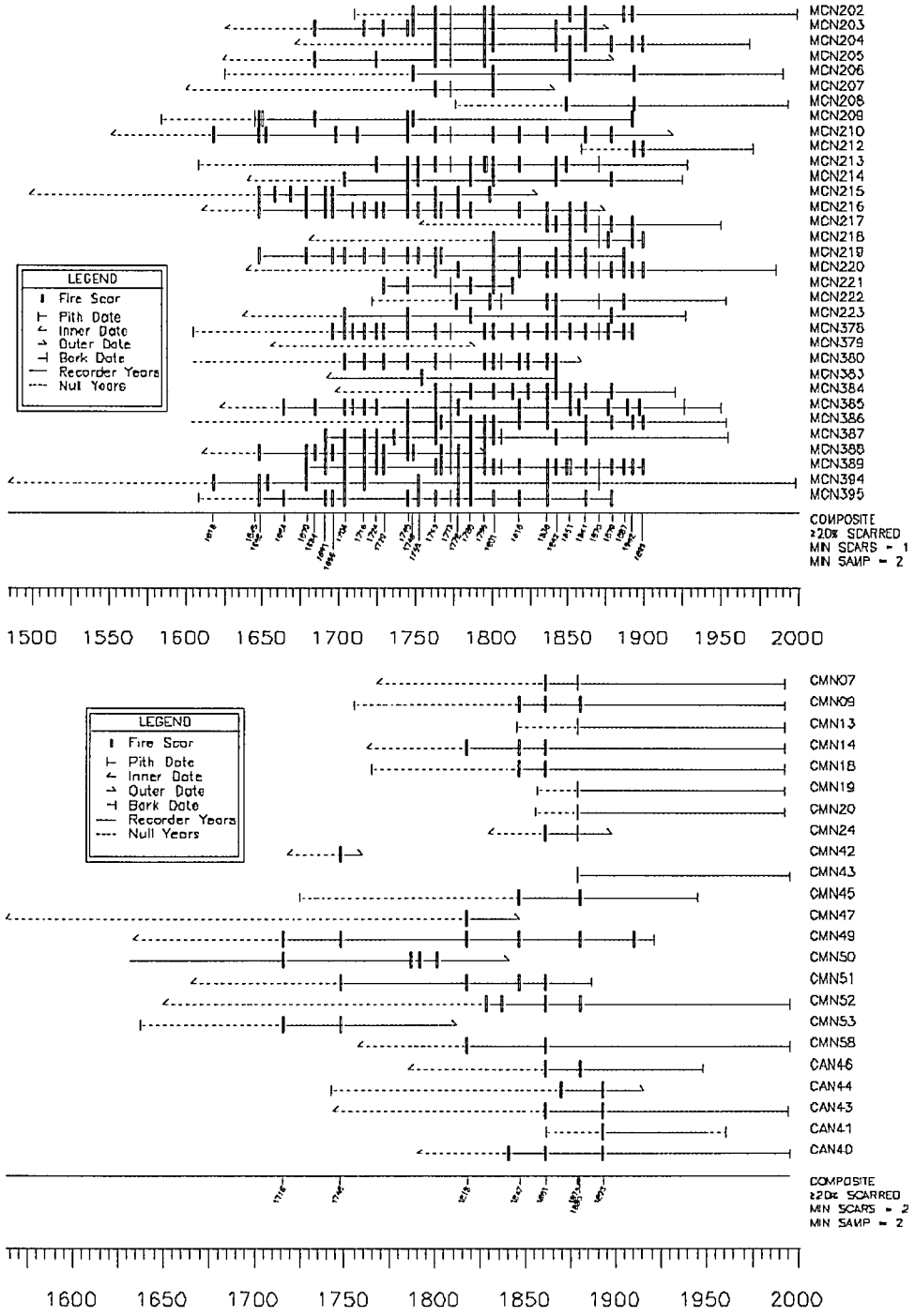


Figure 5. Moving period fire occurrence trends in the five study sites. These graphs show the moving period mean percentage of trees scarred for three window-lengths of the periods (10, 25 and 50 years.

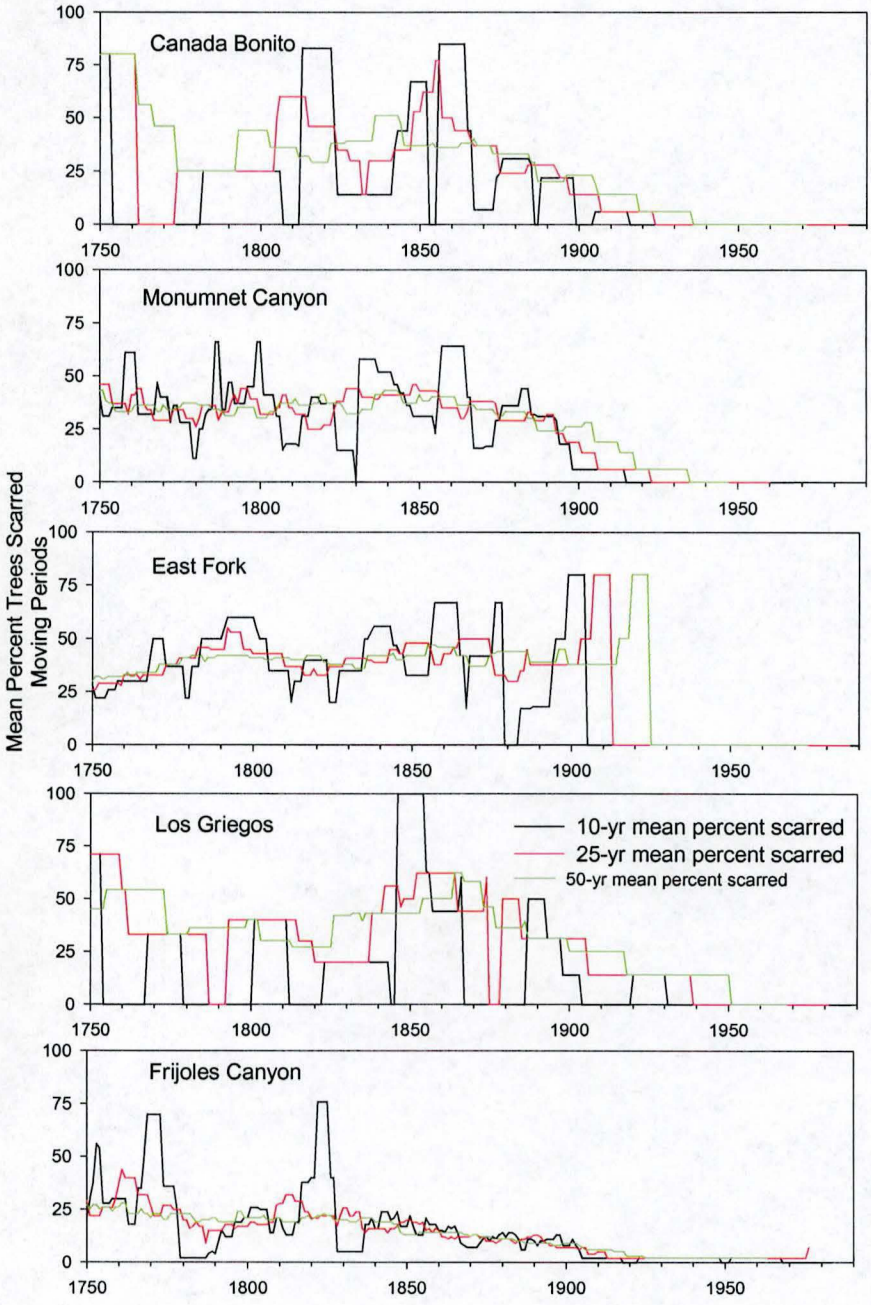


Figure 6. Moving period fire occurrence (red) and budworm outbreak (green) time series are compared. The moving period fire series are the mean percentages of trees scarred during the period (25 year is shown for Canada Bonito and Los Griegos; 10-year is shown for West Vallecitos (Monument Canyon), East Fork, and Frijoles Canyon). The dashed green line is sample depth for the budworm series.

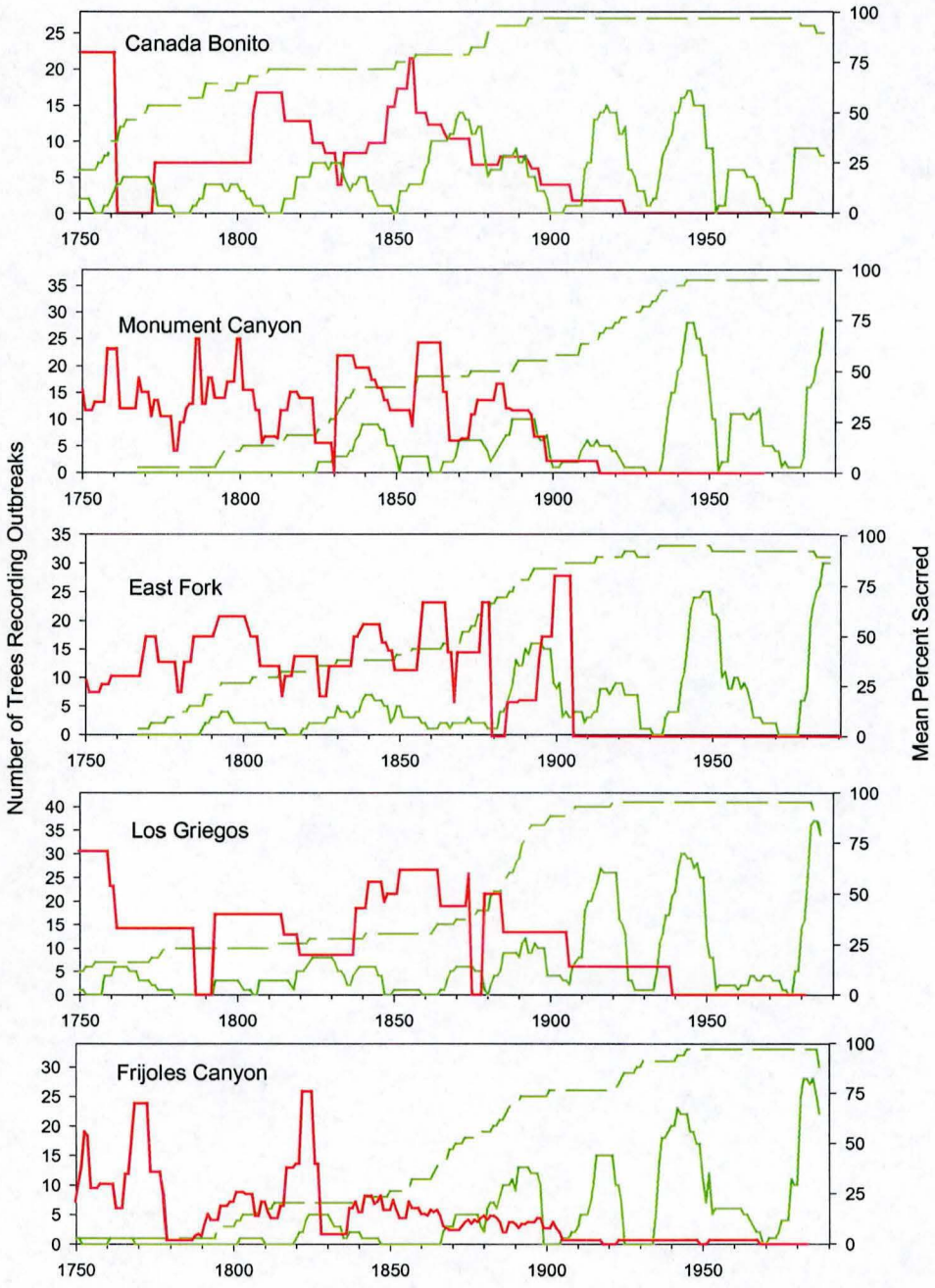


Figure 7. Comparison of composite budworm and fire histories from the Jemez Mountains. The upper graph is the composite budworm time series from all stands in the Jemez with budworm histories. The middle graph is the percentage of trees scarred each year among the five study sites in this paper, plus other fire scar chronologies in Bandelier National Monument and near Canada Bonito (see Fig. 1). The bottom graph is running 20 year mean of percentage trees scarred per year with the sample depth for all of the fire scar chronologies that are included. The gray shaded lines show the approximate timing of outbreak periods in 1600s to 1900s

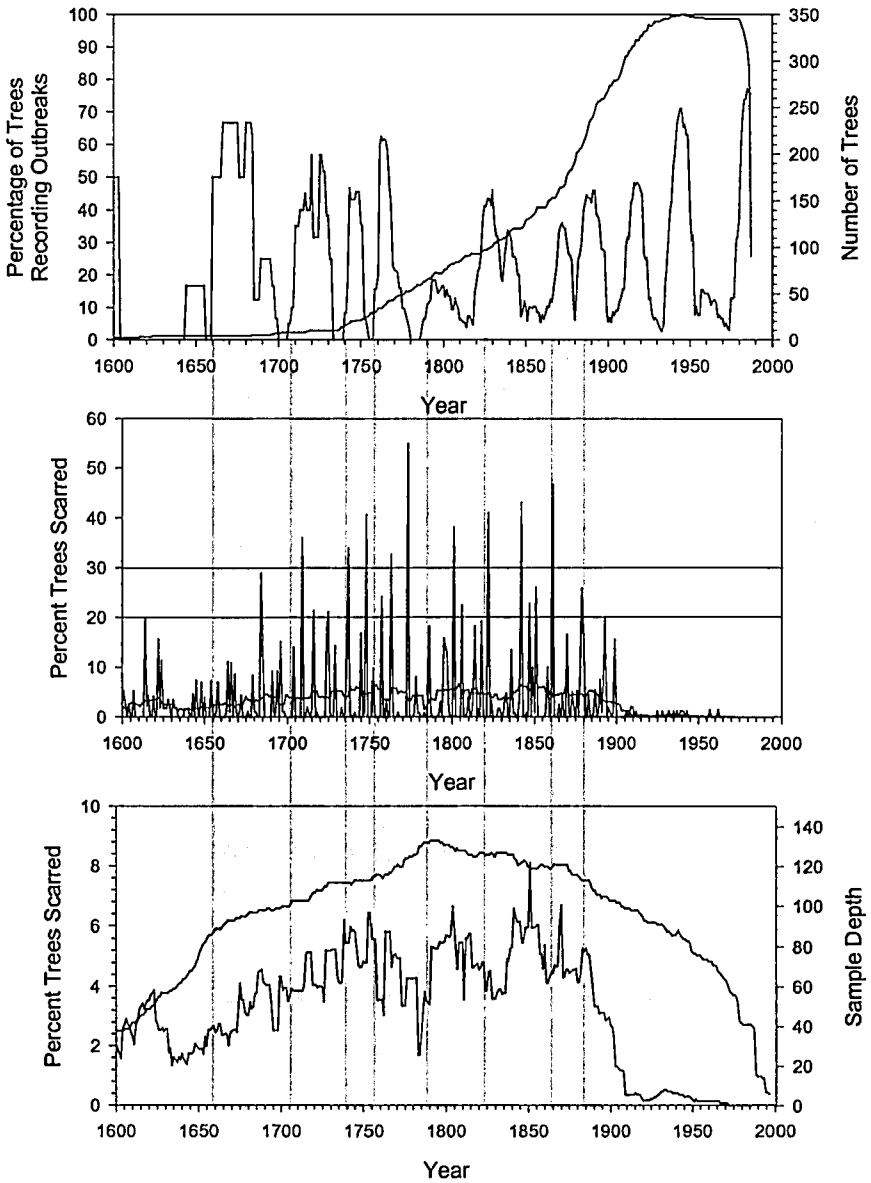
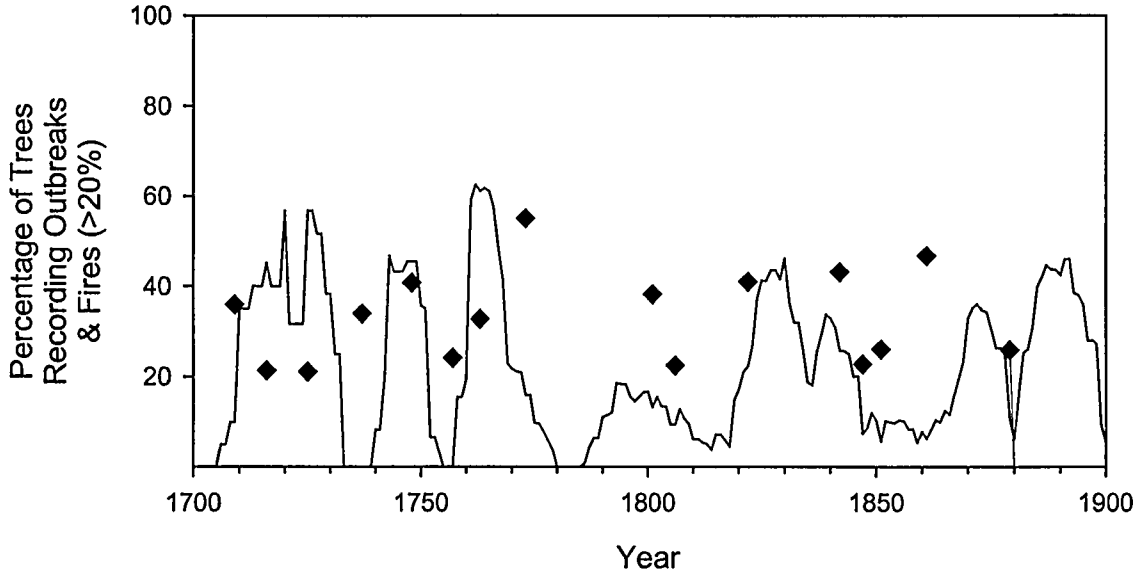


Figure 8. Composite budworm outbreak series compared with most synchronous fire dates (diamonds, >20% of all trees scarred in all sites combined) in the Jemez Mountains, 1700 to 1900.



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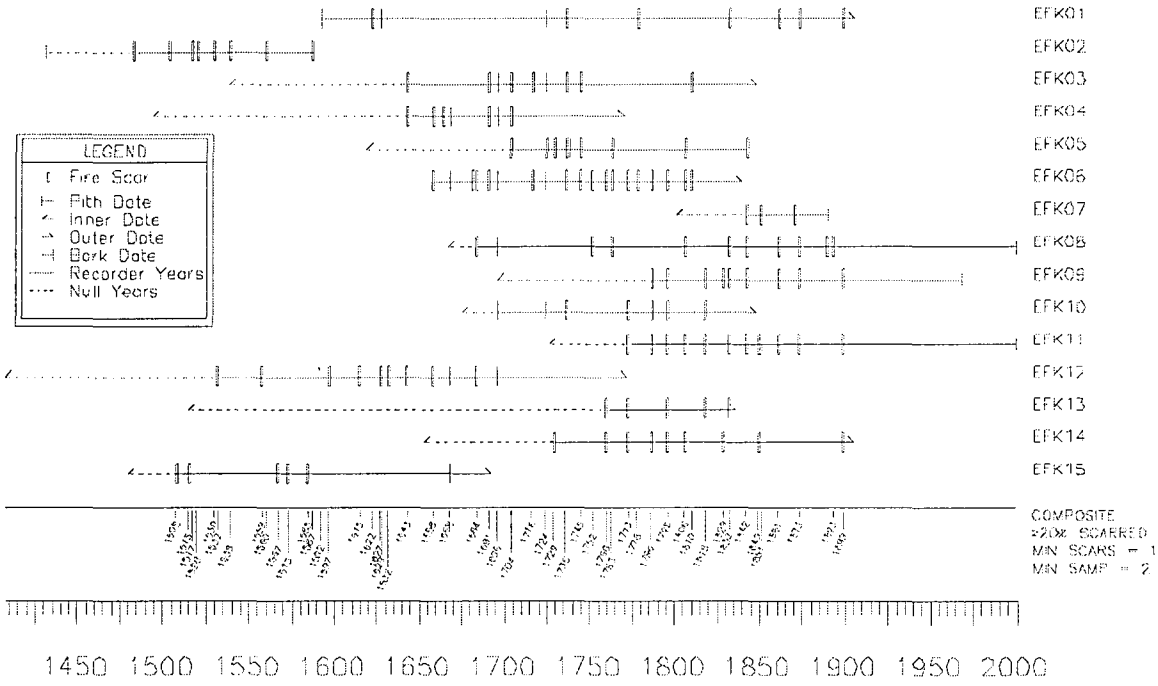
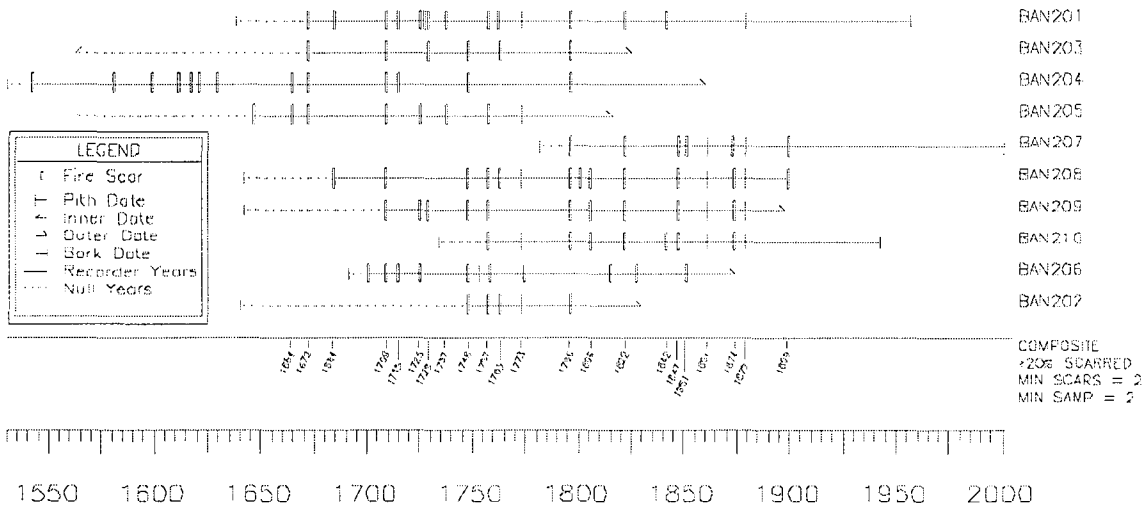
Appendix 1

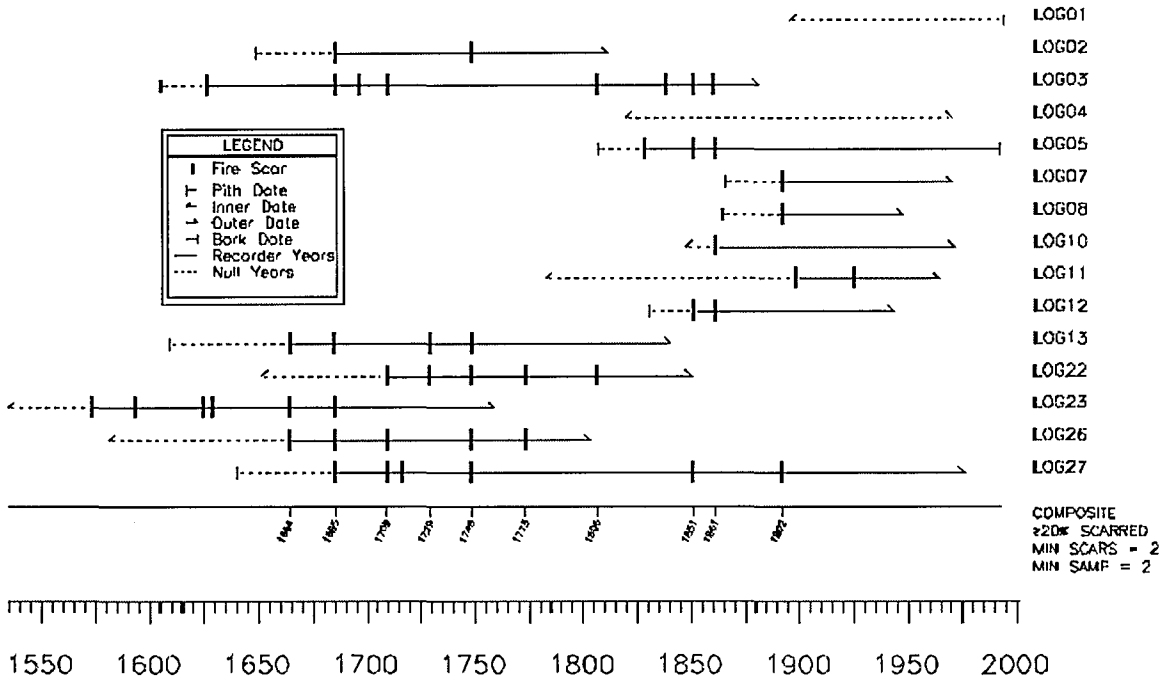
Fire scar chronology in East Fork site.



Fire scar chronology in upper Frijoles Canyon



Fire scar chronology at Los Griegos site.



Fire scar chronology in Bandelier sites 1 to 5.